

# MATERIALS SCIENCE

## SSP 2412

### MATERIAL PROCESSING

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# Introduction

**Materials processing**, the series of operations that transforms industrial materials from a raw-material state into finished parts or products. Industrial materials are defined as those used in the manufacture of “hard” goods, such as more or less durable machines and equipment produced for industry and consumers, as contrasted with disposable “soft” goods, such as chemicals, foodstuffs, pharmaceuticals, and apparel.

# Traditional Manufacturing Processes

Casting

Forming

Sheet metal processing

Powder & Ceramics Processing

Plastics processing

Cutting

Joining

Surface treatment

Others.....

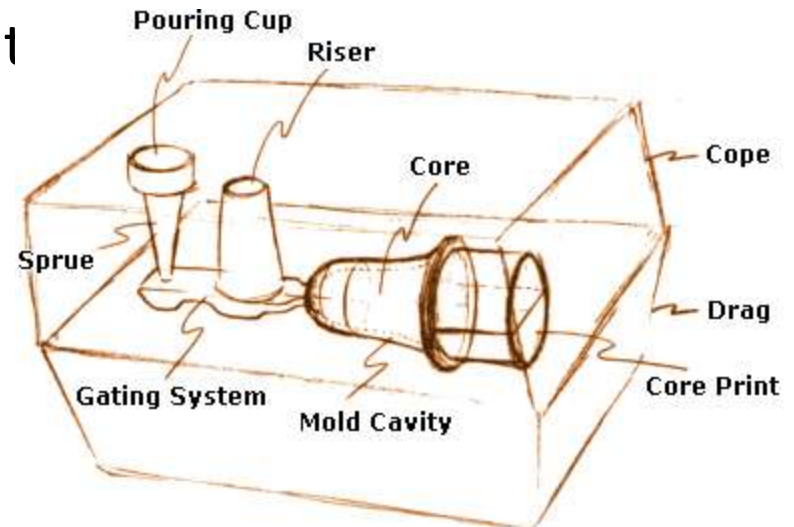
Semiconductor Processing

## **Metal Casting - Casting Process**

- Involves flow of molten metal into mold cavity
  - cavity has a shape of the finished part machined into it. Melt is allowed to cool and solidify. Final product removed from mold.
- Important considerations:
  - flow of melt into cavity
  - solidification and cooling of metal in the mold
  - influence of the type of mould material
- Typical applications:

## Flow of Melt in the Mold

- Melt is poured into mold cavity through a POURING CUP
- Melt flows through the GATING SYSTEM which consists of:
  - Sprue:- vertical channel through which melt flows downward
  - Runners - channels that carry melt from sprue into cavity
  - Gate - part of the runner through which melt enters cavity
- Risers - reservoirs that supply melt during solidification



# Casting Processes

## Expendable Mold

- Sand casting
- Shell molding
- Lost foam process
- Lost wax (investment casting)

## Permanent Mold

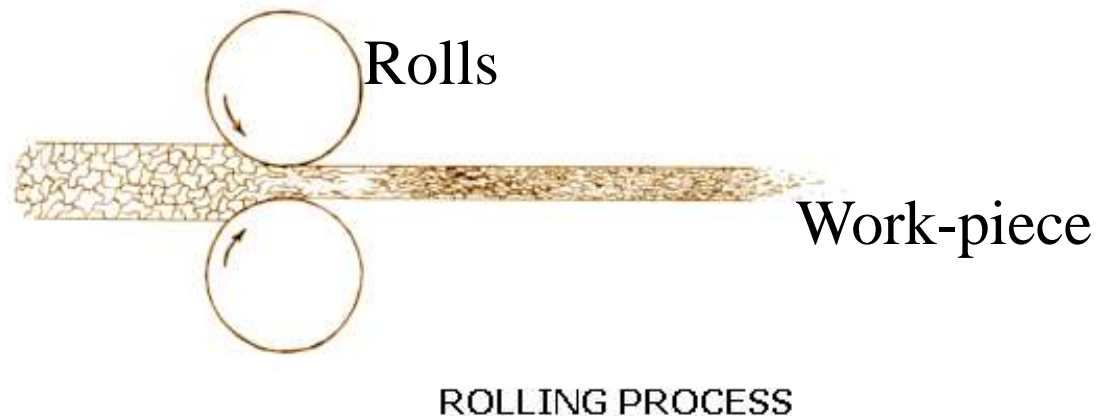
- Die casting
- Centrifugal casting

# Forming and Shaping Processes

- Forming Processes: - involve processes that deform the initial material plastically into a final material - sometimes through various stages
- In both processes, product can be discrete (e.g. a connecting rod) or continuous (e.g. sheet metal)
- Workability - refers to bulk deformation processes. Forces applied are predominantly compressive (e.g. forging). To be studied : Rolling and Forging
- Formability - refers to sheet forming processes in which forces applied are predominantly tensile (e.g. tube drawing). To be studied : Extrusion and Sheet Metal Forming

# Rolling Processes - Introduction

- Process that reduces thickness or changes the cross section of a long work-piece by application of compressive forces through a set of rolls.



- Can be done when the workpiece is cold - COLD ROLLING or when hot (above recrystallization temperature) - HOT ROLLING



## Flat Rolling

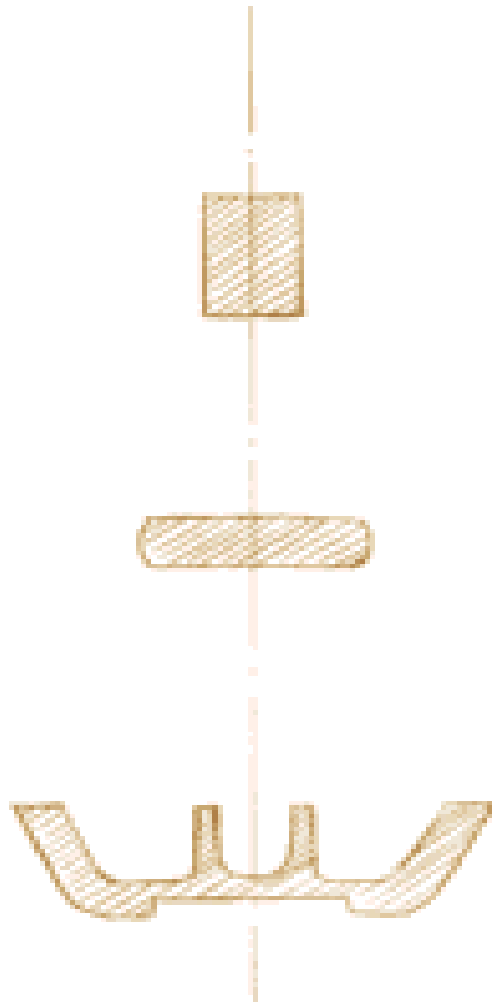
- A sheet or block or strip stock is introduced between rollers and then compressed and squeezed. Thickness is reduced. The amount of strain (deformation) introduced determines the hardness, strength and other material properties of the finished product.
  - Used to produce sheet metals predominantly

- Other Rolling Processes
- Shape or Profile Rolling: - Straight, long structural parts produced with various cross sectional shapes. Profile roles or roll combinations used to achieve this
- Thread Rolling: - used for making external threads. A die with the thread profile, is pressed on to a rotating work-piece.

# Forging Processes - Introduction

- Forging - metal is heated and is shaped by plastic deformation by suitably applying compressive force; hammer blows using a power hammer or a press.
- Forgings yield parts that have high strength to weight ratio - thus are often used in the design of aircraft frame members.
- A Forged metal can result in the following: -
  - Decrease in height, increase in section - open die forging
  - Increase length, decrease cross-section, called drawing out.
  - Decrease length, increase in cross-section on a portion of the length - upsetting
  - Change length, change cross-section, by squeezing in closed impression dies - closed die forging. This results in favorable grain flow for strong parts

## FORGING PROGRESSION



**Sheared Billet**

**Upset Pancake**

**Finished Part**

# Types of forging processes

- Open Die Forgings / Hand Forgings
  - E.g. traditional blacksmith
- Heading - Upsetting process that increases cross-section by compressing a portion of the length (hot or cold)
  - this is used in making heads on bolts and fasteners, valves and other similar parts



COLD HEADING/COLD FORGING

# Types of forging processes

- Impression Die and Closed Die Forgings
  - Example – alloy ream
  - Coining

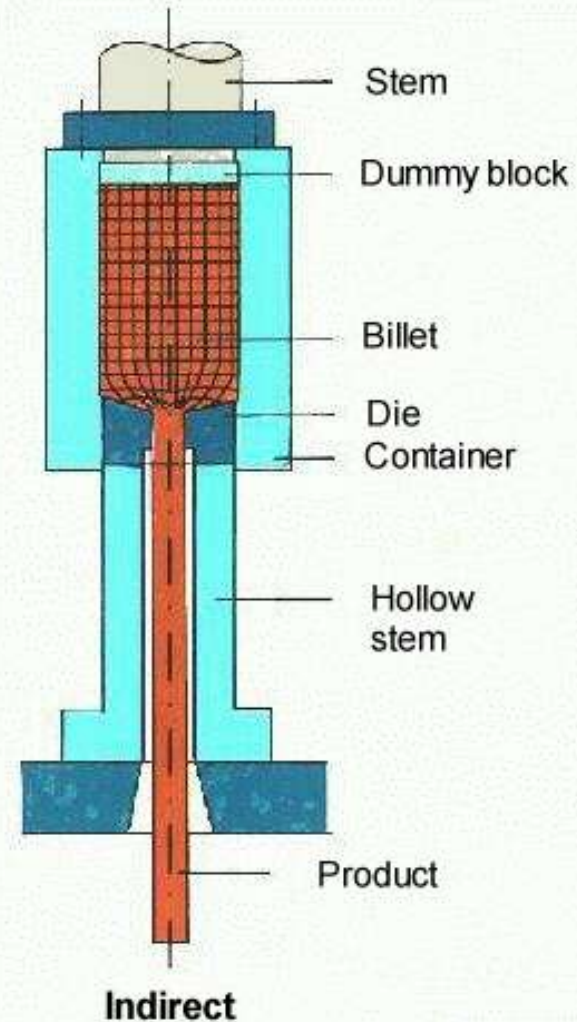


## Extrusion and Drawing Processes

- **Extrusion** - Process by which long straight metal parts can be produced.
- Cross-sections that can be produced vary from solid round, rectangular, to L shapes, T shapes, tubes and many other different types
- Done by squeezing metal in a closed cavity through a die using either a mechanical or hydraulic press.
- Extrusion produces **compressive** and **shear** forces in the stock.
- No tension is produced, which makes high deformation possible without tearing the metal.
- Can be done Hot or cold

- Indirect Extrusion - Reverse or backward extrusion- Die moves towards billet

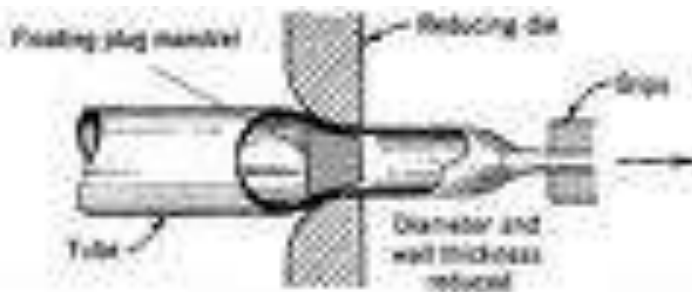
- Billet also upsetted first in the container
- a dummy block used to lock the container from one side
- a hollow stem pushes die into the billet OR dummy block and container may push billet through die and hollow container (smaller friction)





# Drawing - X section of material reduced by pulling through die

- Similar to extrusion except material is under **TENSILE** force since it is pulled through the die
- Various types of sections : - round, square, profiles
- Tube Drawing: - Utilizes a special tool called a **MANDREL** is inserted in a tube hollow section to draw a seamless tube



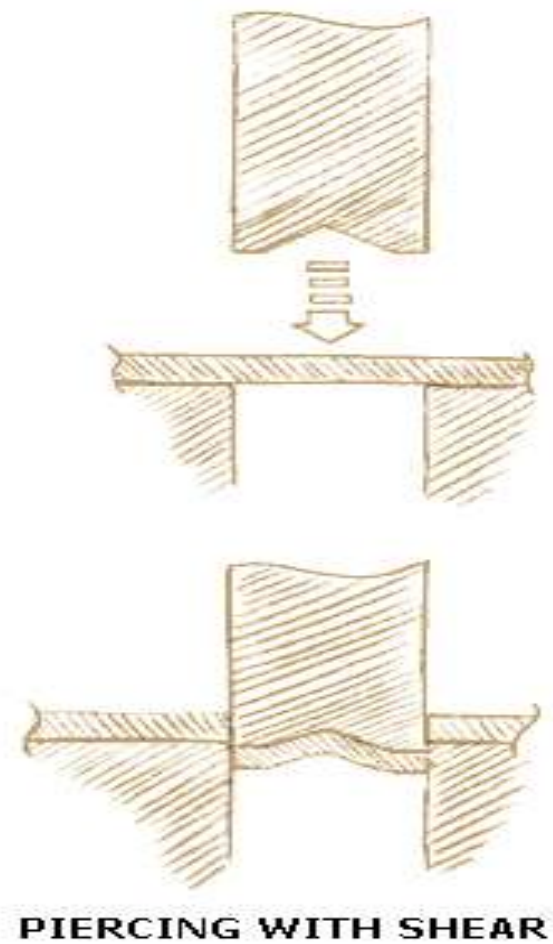
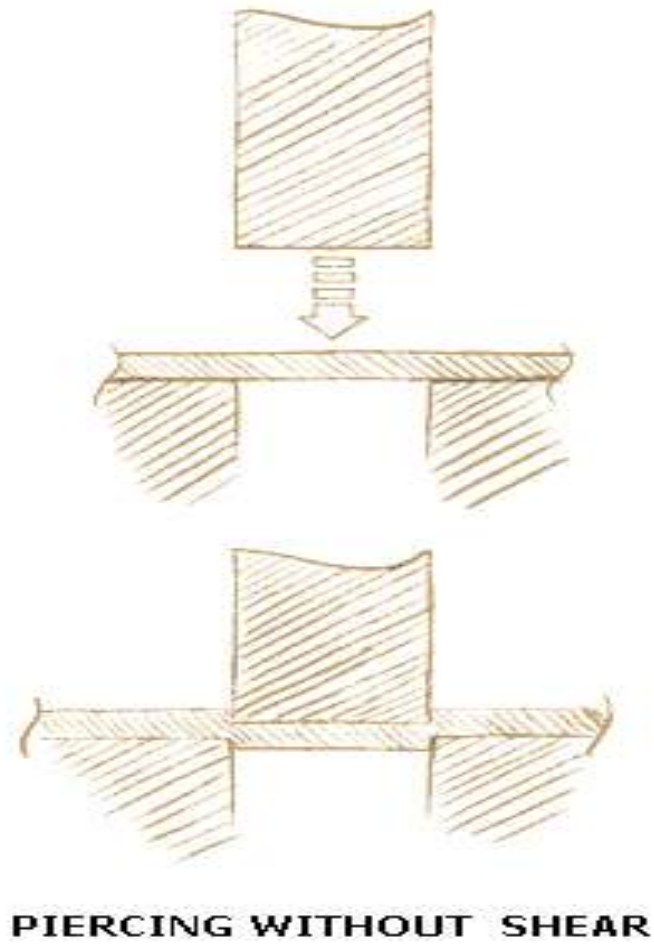
Mandrel and die reduce both the tube's outside diameter and its wall thickness. The mandrel also makes the tube's inside surface smoother

## Sheet Metal Forming - Introduction

- Involves methods in which sheet metal is cut into required dimensions and shape; and/or forming by stamping, drawing, or pressing to the final shape
- A special class of metal forming where the thickness of the piece of material is small compared to the other dimensions
- Cutting into shape involve shear forces
- Forming Processes involve tensile stresses

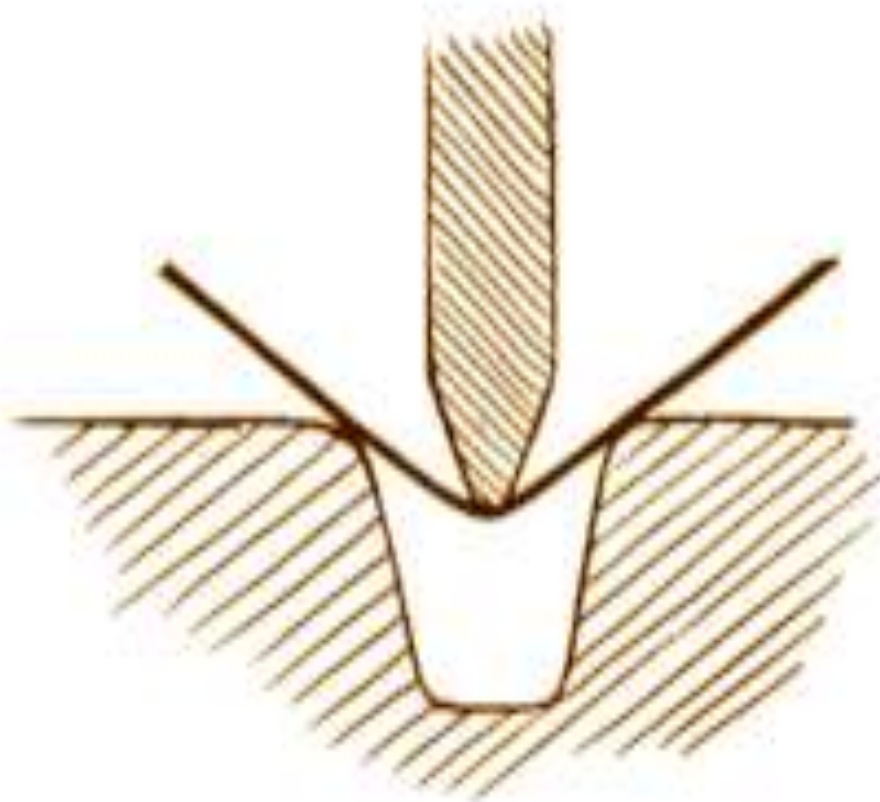
# Shearing

- Process for cutting sheet metal to size out of a larger stock
- Shears are used as the preliminary step in preparing stock for stamping processes, or smaller blanks for CNC presses.
- Sheet is cut by subjecting it to a shear stress



# Bending

- Bending is a process by which metal can be deformed by plastically deforming the material and changing its shape
  - Flexible; different shapes can be produced
- Standard die sets can be used to produce a wide variety of shapes



Air-Bending



Bottoming

- **Other Bending Processes:**
- Press brake bending - used to form for example seam joints
- Roll bending
- Beading
- Flanging, dimpling, hemming

# Deep Drawing

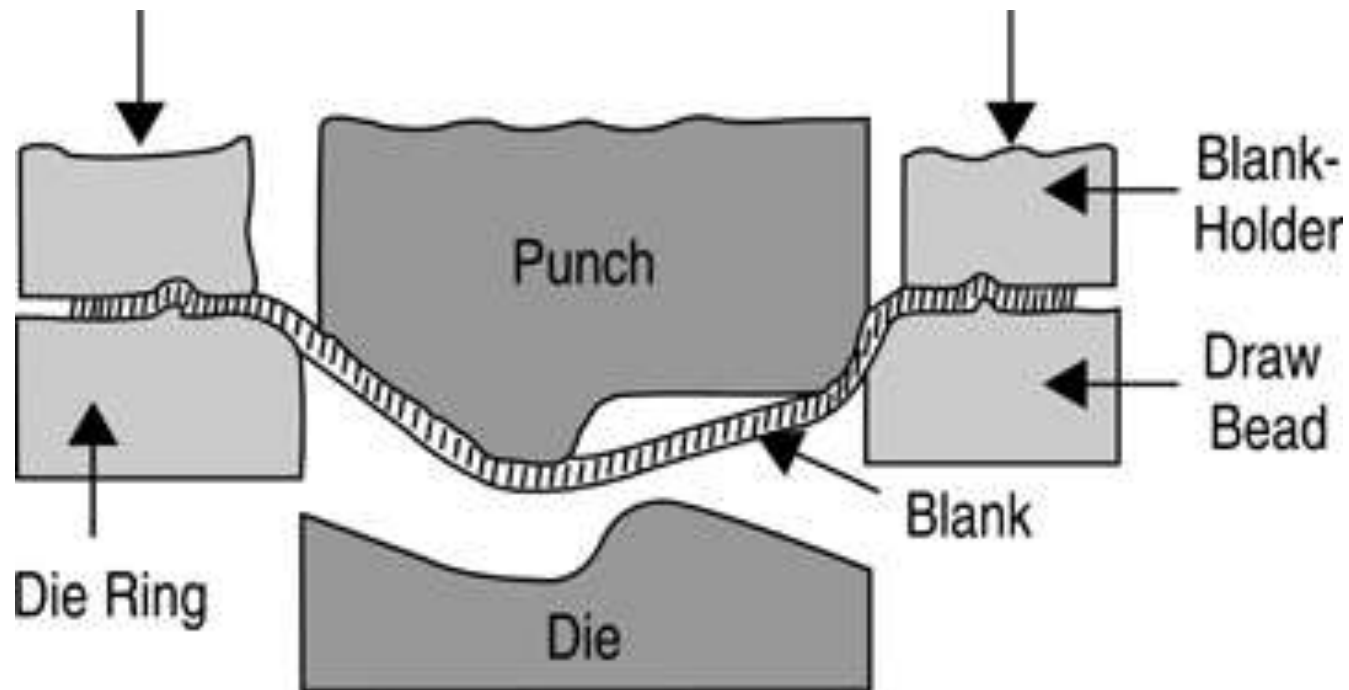
- In deep **drawing**, a blank of sheet metal is restrained at the edges by BLANKHOLDER, and the middle section is forced by a punch into a die to stretch the metal into a cup shaped drawn part. This drawn part can be circular, rectangular or otherwise





# Stamping

- Variety of operations e.g. punching, blanking, embossing, coining



## Others:

- Roll bending
- Beading
- Flanging
- Roll forming
- Tube bending and forming

# Processing of Powder - Metallurgy (P/M)

- Process by which metal parts are made by compacting fine metal powders in a die and heating without melting (SINTERING)
- Produces mostly “NET” shapes
- Most commonly used metal powders are iron, copper, aluminum, tin, nickel, titanium, and refractory alloys
- Major attraction of P/M is the ability to fabricate high quality parts with complex shapes to close tolerances in an economical manner; highly porous parts, precision parts of high performance as well as composite materials can be produced by P/M
- Process consists of:
  - 1-Powder production
  - 2-Blending
  - 3-Compaction
  - 4-Sintering
  - 5-Finishing operations

## Applications of P/M

- Tungsten lamp filaments, dental fillings, oil less bearings, automotive transmission gears, electrical contacts, orthopedic implants, high temperature filters, aircraft brake pads and landing gear, impellers in APU's



# Processing of Ceramics

- Generally procedure involves:
  - Crushing/grinding (Comminution) material into very fine particles
  - Mixing with additives to impart certain characteristics
  - Shaping
  - Drying
  - Firing

# Forming and Shaping of Glass

Process involves: -

- Melting
- Shaping in Molds or other devices
- Strength improvements obtained by chemical and thermal treatments or by laminating with a thin plastic (Auto glass)
- Types of Products:
  - sheet or plate
  - rods and tubes
  - discrete products (e.g. bottles)
  - glass fibers (for composite reinforcement)

- Methods of Processing: -

- a) Flat sheet plate

- Drawing - molten glass drawn through a pair of rolls
- Rolling - molten glass squeezed between rolls
- Float method - molten glass floats into a bath of molten tin under controlled atmosphere; then drawn out by a set of rolls. Smooth surface finish

- b) Tubes and Rods -

- Tube: - Molten glass wrapped around a mandrel (hollow or conical) and drawn by a set of rolls; air is blown through the mandrel to prevent tube wall from collapsing
- Rod: - Similar except no mandrel.

### c) Glass Fibers: -

- Long fibers - drawing through multiple orifices in heated platinum plates at high speeds
- Short fibers - molten glass fed into rotating head -  
**CENTRIFUGAL SPRAYING**

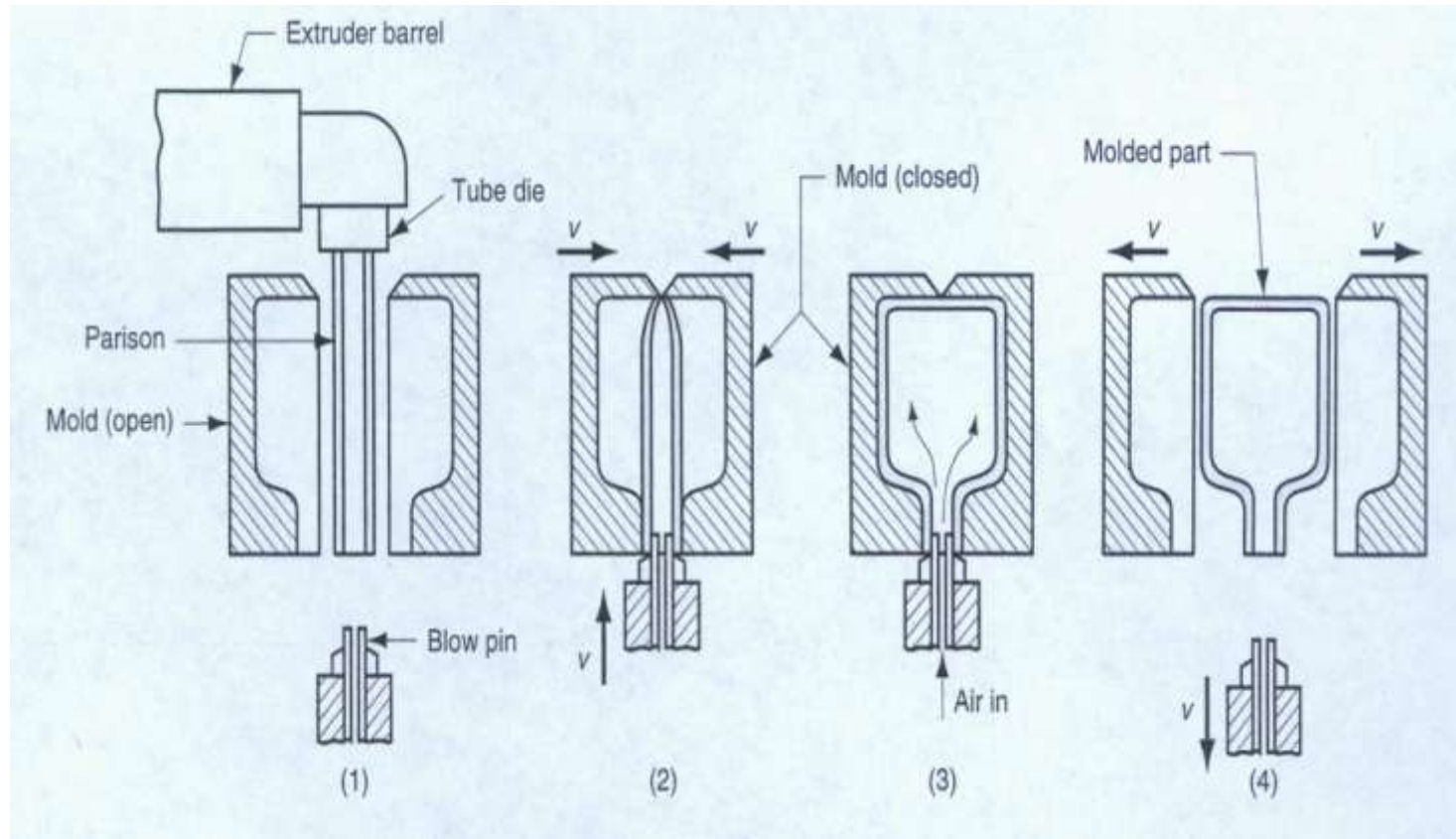
### d) Discrete parts: - Several methods.

- Blowing - used to manufacture thin walled products such as bottles or flasks
- Pressing :- Molten glass pressed into shape in a mold
- Centrifugal casting or spinning : -centrifugal force forces molten glass onto rotating mold walls and cools into shape



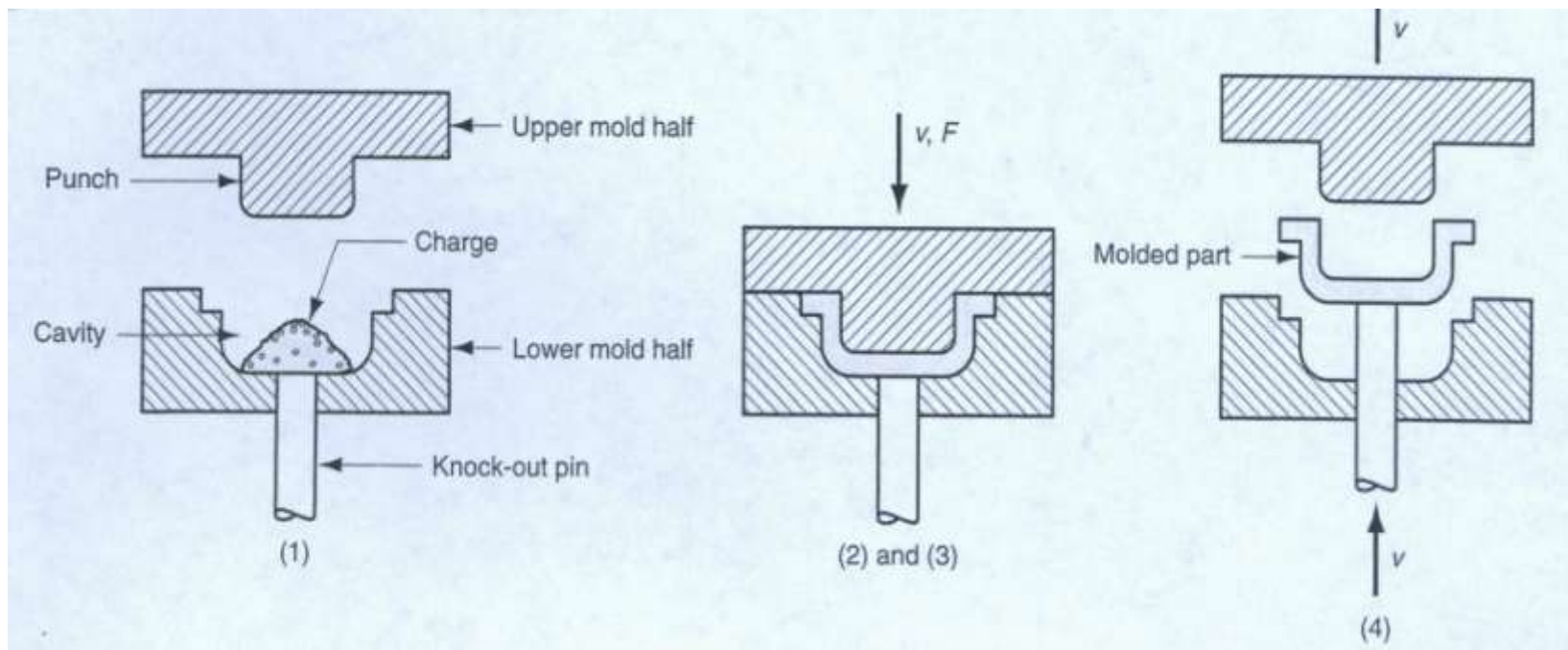
# Processing of Polymers

1. Casting – molten polymer allowed to solidify inside a mold cavity to acquire the desired shape. For thermosets, additional curing may be necessary. Examples: thermoplastic sheets & plates thermoset lenses, gears
2. Blow Molding- used to make thermoplastic bottles and hollow sections. Starting material is a a round heated solid-bottom hollow tube – preform. Preform inserted into two die halves and air is blown inside to complete the process

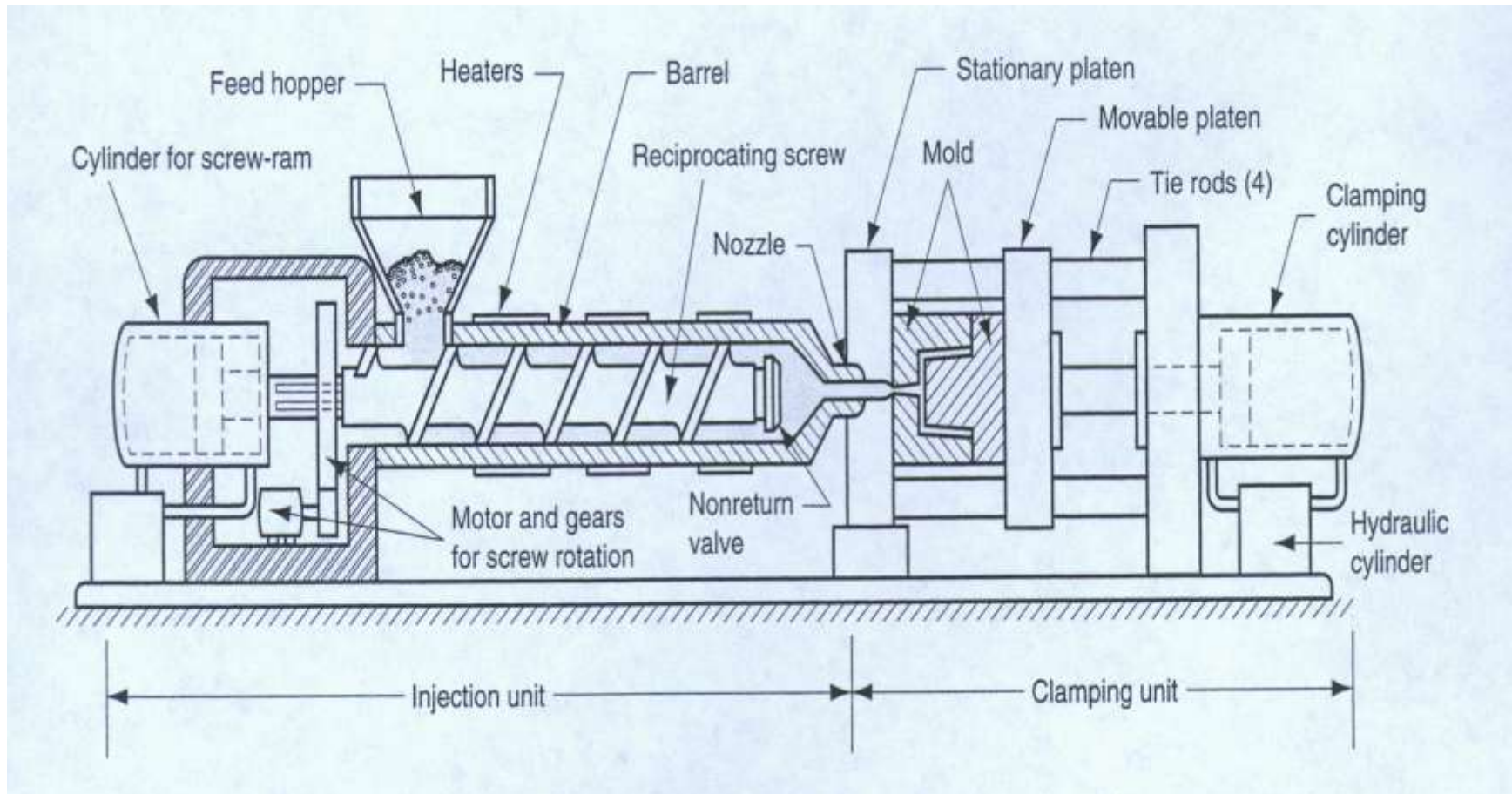


## Blow molding process

3. Compression Molding – thermoset granules are “compressed” in a heated mold to shape required. Examples: plugs, pot handles, dishware



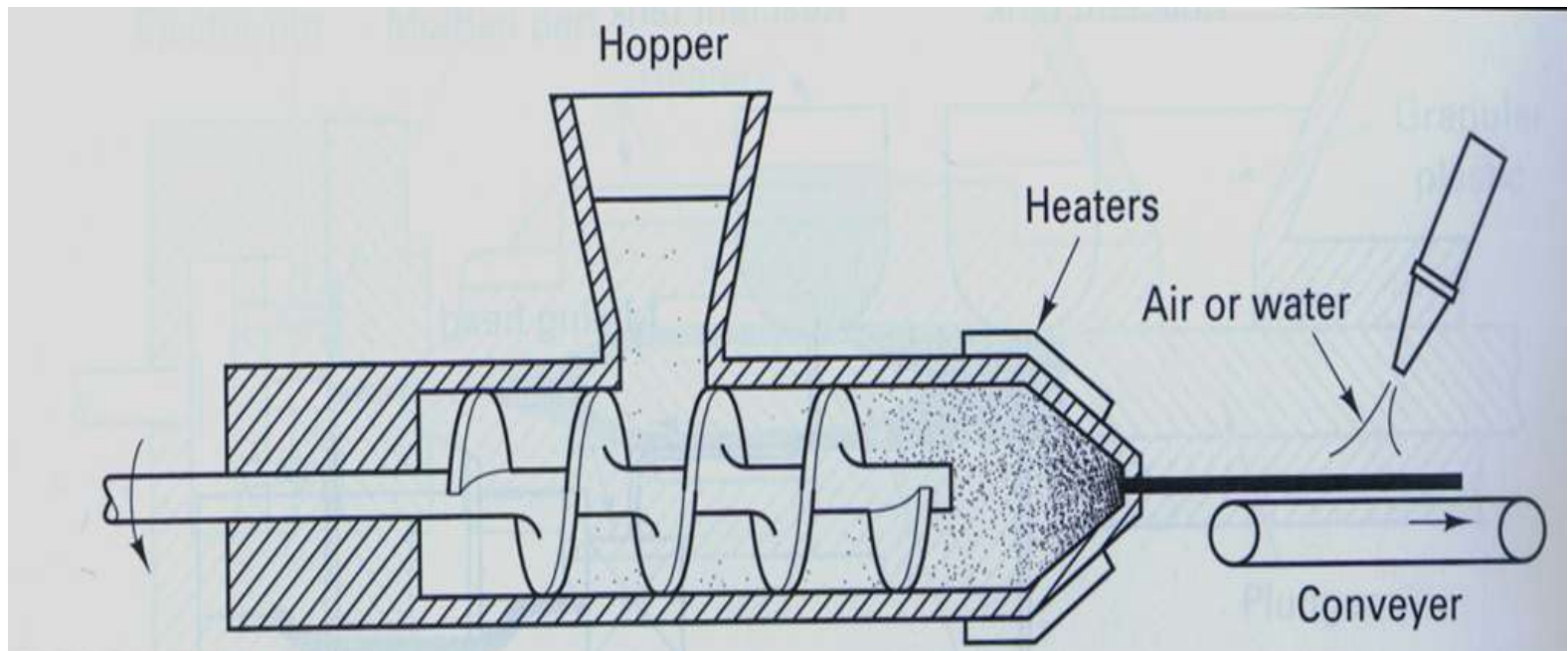
4. Transfer Molding – similar to compression molding except thermosetting charge is forced into a heated mold cavity using a ram or plunger.  
Examples: electrical switchgear, structural parts
5. Cold Molding – charge is pressed into shape while cold then cured in an oven. Economical but usually poor surface finish
6. Injection Molding – Most widely used process. Suitable for high production of thermoplastics. Charge fed from a hopper is heated in a barrel and forced under high pressure into a mold cavity. Several types. Variety of parts can be made.



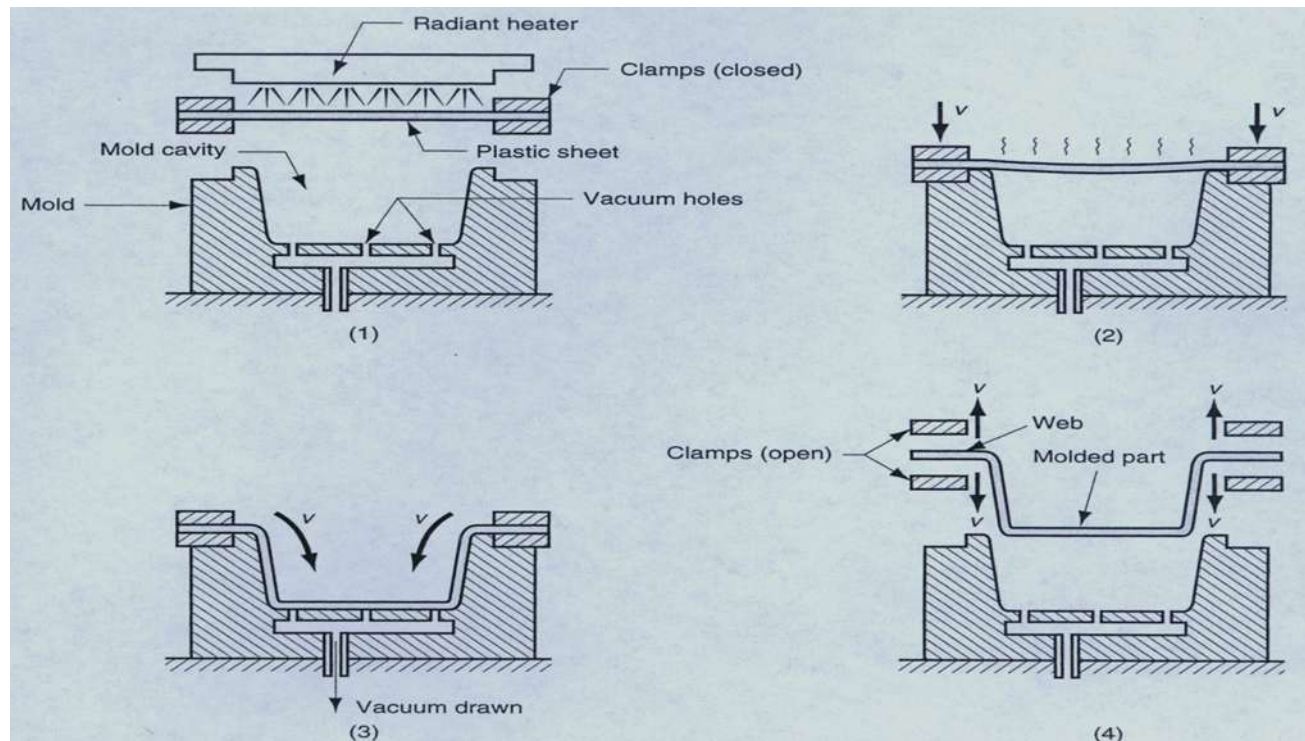
## Example of an injection molding system



7. Extrusion – Similar to injection molding except long uniform sections are produced –e.g. pipes, rods, profiles



8. Thermoforming – Sheet material heated to working temperature then formed into desired shape by vacuum suction or pressure. Suitable for large items such as bath tubs



9. Rotational Molding – used to form hollow seamless products such as bins. Molten charge is rotated in a mold in two perpendicular axes simultaneously, or rotated while tilting.
10. Foam Molding – Foaming agent is combined with the charge to release gas, or air is blown into mixture while forming. Used to make foams. Amount of gas determines the density



## 11. Others-

- Calendaring: molten plastic forced between two counter-rotating rolls to produce very thin sheets e.g. polyethylene sheets
- Spinning: modified form of extrusion in which very thin fibers or yarns are produced
- Machining: material removal process such as drilling, turning, thread cutting. E.g. nylon fasteners. In general thermoplastics have poor machinability.

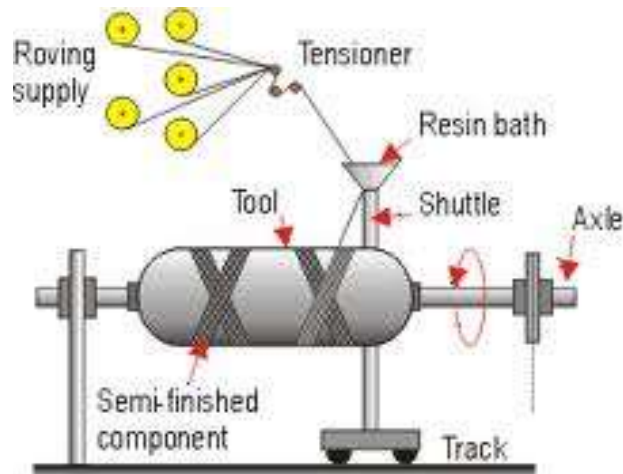
# Composite Materials

- Processing requires care and several methods
- Safety and environmental concern over the dust generated from particles
- For good bonding with matrix, fibers are surface treated by impregnation - SIZING
- When impregnation is carried out as a separate step, several types of partially cured sheets can be produced:
  - Prepreg: - Reinforcing material aligned and impregnated with resin prior to the molding process and cured by the application of heat. Example F14 horizontal stabilizer.

- Sheet Molding Compound (SMC) - continuous strands of fibers cut into short strands then deposited in random directions over layer of polymer resin., a second layer of resin deposited on top and material pressed between rolls. Allowed to mature under controlled temperature and humidity
- Bulk molding compounds (BMC) - material is bulky or shaped like a billet, but processing similar to SMC
- Thick Molding compound (TMC) - combines characteristics of BMC and SMC.
- Methods of Processing include Molding, Filament Winding, Pultrusion, Pulforming

- Molding: - Several types of molding processes:
  - Compression molding: - composite material compressed under heat in a mold
  - Vacuum-bag molding: - prepregs laid in a mold to form desired shape, then covered with plastic bag. Pressure to form is obtained by applying a vacuum to the bag
  - Contact molding: - Uses a single mold to make shapes like boats. Lay-up of prepreg may be manual using rollers and brushes - HAND LAY-UP or by SPRAY LAY-UP
  - Resin Transfer Molding :- Resin mix forced into mold cavity that is filled with reinforcement, through a pump
  - Transfer/injection Molding:- combines transfer and injection molding in an automated process

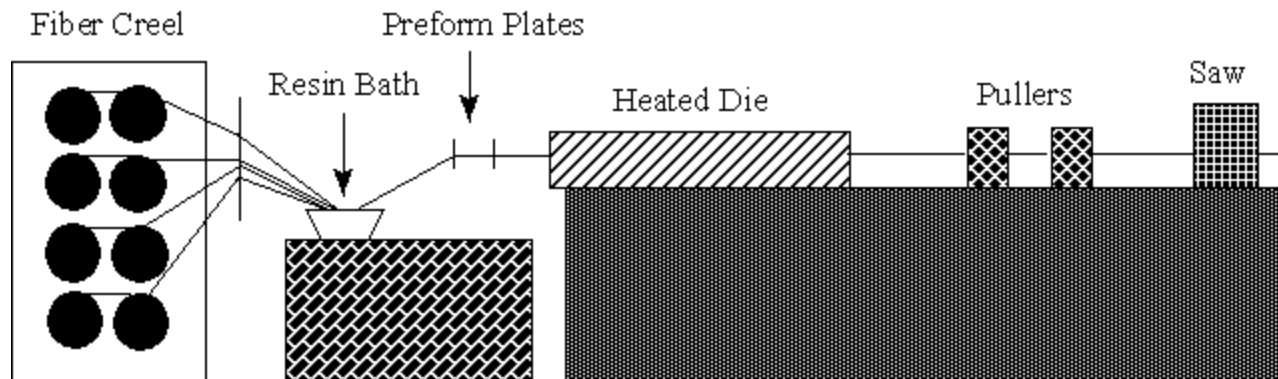
- Filament Winding:- involves winding a resin-saturated strand of reinforcing filament around a rotating mandrel until desired thickness is obtained. Used for axisymmetric parts - pipes, storage tanks; asymmetric parts - aircraft fuselage, propeller blades



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- Pultrusion:- fibers are brought together over rollers, dipped in resin and drawn through a heated die. A continuous cross section composite part emerges on the other side. Very applicable for long shapes with uniform sections such as rods, or even pipes



Schematic Diagram of the Pultrusion Process

- Pulforming:- used to make continuous products not necessarily having uniform cross section. After pulling through a polymer bath, composite is cured inside to heated die halves into required shape.

# **Other Processing**

**Rapid Prototyping**  
**Material Removal Processes**  
**Welding and Joining Processes**

(NOT COVERED HERE)